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On the non-evolution of the dependence of black hole masses on bolometric luminosities for QSOs

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Abstract   There are extremely luminous quasi stellar objects (QSOs) at high redshift which are absent at low redshift. The lower luminosities at low redshifts can be understood as the external manifestation of either a lower Eddington ratio or a lower mass. To distinguish between both effects, we determine the possible dependence of masses and Eddington ratios of QSOs with a fixed luminosity as a function of redshifts; this avoids the Malmquist bias or any other selection effect. For the masses and Eddington ratios derived for a sample of QSOs in the Sloan Digital Sky Survey, we model their evolution by a double linear fit separating the dependence on redshifts and luminosities. The validity of the fits and possible systematic effects were tested by the use of different estimators of masses or bolometric luminosities, and possible intergalactic extinction effects. The results do not show any significant evolution of black hole masses or Eddington ratios for equal luminosity QSOs. The black hole mass only depends on the bolometric luminosity without significant dependence on the redshift as $\left(\frac{M_{BH}}{10^9\,M_\odot}\right) \approx 3.4 \left(\frac{L_{bol}}{10^{47}\,\mathrm{erg/s}}\right)^{0.65}$ on average for $z \leq 5$. This must not be confused with the possible evolution in the formation of black holes in QSOs. The variations of environment might influence the formation of the black holes but not its subsequent accretion. It also leaves a question to be solved: Why are there not QSOs with very high mass at low redshift? A brief discussion of the possible reasons for this is tentatively pointed out.

Key words: accretion –methods: statistical— quasars: general

1 INTRODUCTION

Quasi stellar objects (QSOs) are extremely bright at high redshift, but at low redshift they are much less luminous; in fact from the analysis of the bolometric luminosity function of QSOs at different redshift (Hopkins et al. 2007), it is clear that the relative abundance of high luminosity QSOs decreases quickly at low redshift. In the Sloan Digital Sky Survey (SDSS), all QSOs at $z < 0.4$ are fainter than $M_B = -26$ (with K-corrections) while there are numerous QSOs tens of times brighter than this limit at higher redshifts. The same effect is also observed in other spectral ranges; for instance in X-rays (Shen et al. 2006) or in radio (Bridle & Perley 1984; Bell 2006, Figs. 9, 10). All these observations require a strong density and luminosity evolution.

Something very different must have happened at high redshift with respect to the low redshift Universe to obtain this different level of luminosity. However, no visible signs of this evolution are

observed. There is no indication of any significant evolution in the X-ray properties of quasars between redshifts 0 and 6, apart from the intrinsic luminosity, suggesting that the physical processes of accretion onto massive black holes have not changed over the bulk of cosmic time (Vignali et al. 2005). Also, the spectral features of low and high redshift QSOs are very similar (Segal & Nicoll 1998). This strong change in luminosity without any additional external sign of evolution is one of the most relevant pending problems in QSOs (López-Corredoira 2011).

There are two possible reasons for the lower luminosity of low z QSOs with respect to those ones with high z: 1) either their black holes are less massive, and this would explain the lower power of their accretion disks, 2) or they have obtained approximately the same mass but they are less efficient, due to a lower accretion rate. There are several works that estimated masses and Eddington ratios of QSOs' black holes (McLure & Dunlop 2004, Kollmeier et al. 2006, Vestergaard & Peterson 2006, La Mura et al. 2007, Vestergaard et al. 2008, Shen et al. 2008 [herein S08], Labita et al. 2009a,b). The result in general is that masses and Eddington ratios are larger at higher z. Nonetheless, it cannot be directly interpreted as a sign of evolution of QSOs because the samples used are strongly affected by the Malmquist bias, that is, we are comparing low luminous QSOs at low z with high luminous QSOs at high z. S08 made a separation in bins of fixed luminosity showing qualitatively that much of this apparent evolution is due to luminosity variation. We think that this analysis requires further attention in order to properly quantify it and the possible systematics involved. This is the main aim of this paper in which we develop a simple method to study the dependence of black hole masses and Eddington ratios on their redshifts and luminosities.

2 SAMPLE AND METHODOLOGY

A complete and exhaustive compilation of masses and bolometric luminosities of QSOs from SDSS is provided by S08, who determined the masses from the continuum and width of the broad emission lines of H_β, MgII-2798Å or CIV-1549Å in the ranges $z < 0.7$, $0.7 < z < 1.9$ and $1.9 < z < 5.0$ respectively. The total number of objects cataloged by S08 is 77,429. Shen et al. (2011) contains that information for 105,783 QSOs obtained from a more recent version of SDSS, but we still use S08 since we have carried out our analyses with this sample, and we do not expect any significant improvement in our results by just adding 30-40% more QSOs. From this catalog we selected those objects for which there are reliable estimation of masses and luminosities. We imposed some additional constraints based on the width of the lines ($FWHM > 2000$ Km/s) and the SNR (> 5) of the continuum. So, the sample selected has 49,213 objects with an average redshift of $\langle z \rangle = 1.35$. From the black hole masses, M_{BH}, and the bolometric luminosities, $L_{bol.}$, it is straight forward to determine the Eddington ratio

$$\epsilon = \frac{L_{bol.}}{L_{Edd.}}, \tag{1}$$

where $L_{Edd.}$ is the Eddington luminosity (given by e.g., Kembhavi & Narlikar 1999, eq. (5.26)):

$$L_{Edd.} = 1.3 \times 10^{38} \left(\frac{M_{BH}}{M_\odot} \right) \text{ erg/s} \tag{2}$$

In order to avoid the Malmquist bias, we separate the dependence of the interesting quantities on redshifts and on luminosities in the following way: given a variable r, dependent on the redshift (z) and the absolute magnitude with K-correction ($M_{i,rest}$, AB-magnitude) as independent variables, we model the dependence of such variables as a bi-linear function of redshift and luminosity

$$r = a + bx + cy, \tag{3}$$

$$x \equiv f(z); y \equiv g(M_i).$$

We use $f(z) = z$, $g(M_i) = M_i + 23$. The double linear fit of the points $r_i(x_i, y_i)$ gives us the values of a, b and c; i. e. in this way we separate the dependence on redshift and luminosity. The coefficients b

and c are easy to interpret as the ratio of evolution with redshift and luminosity respectively. The model is extremely simple and in principle the dependence might contain non-linear terms, but in any case, b and c will reflect the "average" gradients in the dependence on z and M_i. We do not say that given a luminosity and a redshift there will be only one possible value of r; we do not claim that the deviation of r from luminosity is due to redshift alone o vice verse. However, we can talk about an average dependence on z and M_i. Given a set of QSOs with the same luminosity and the same redshift, we will measure an average mass and an r.m.s. value due to both the possible dependence on other variables and the errors in the measurements. On the other hand, the analysis of the residuals between the data and our simple bi-linear model indicates that the fit is a good description of the data (see below).

Table 1 presents the values of the fits for $r = \log_{10} M_{BH}$ and $r = \log_{10} \epsilon$. Figures 1 and 2 show the average values in bins of redshift and absolute magnitude of these masses and Eddington ratios and the differences between the data and the fit. Only bins enclosing at least 10 objects have been considered in these plots. The maximum difference between the data and the model is 0.15 dex with no clear dependence of these differences on redshift or magnitude. These mean differences per bin are 0.067 for both the mass and the Eddington ratio fits. So, we conclude that our simple bi-linear models are good description of the data.

As said above, we do not claim here that masses (or Eddington ratios) only depend on the luminosities and the redshifts. There may be dependence on other parameters. We are analyzing $\langle M_{BH} \rangle$ in bins of fixed luminosities and redshifts; we do not analyze the exact value of M_{BH} for each QSO. For a given luminosity and a given redshift, the full range of velocities is observed (within $FWHM > 2000$ km/s), because the constraint of 5σ in SNR only affects to the continuum of the line which is not dependent on the velocity, there is not a bias due to a truncation in the velocity range.

The masses determined with H_β and MgII-2798Å agree quite well each other (McLure & Dunlop 2004, S08). The results shown in Table 1 indicate that the coefficients of the fits for the ranges $z \leq 0.7$ and $0.7 < z \leq 1.9$ are quite similar. Masses at redshifts $z \geq 1.9$ were determined from CIV-1549Å lines, and have a large uncertainty as has been shown by several authors (Vestergaard & Peterson 2006, S08, Netzer 2010). However, we do not find within that range of redshift any dramatic change in the general trend of the fits when objects at $z > 1.9$ are included, and then we concluded that it is possible to use the masses statistically determined from CIV. Anyway, because of the given reasons, results at $z \leq 1.9$ are more robust.

As expected for a fixed redshift, there is a strong dependence of both masses and Eddington ratios on luminosity. There is no surprise in that dependence because it is explicit in the virial theorem (see Eq. (3.1) for another formulation of it), which we used to derive mass through the direct relationship with luminosity, and is also implicit in the possible dependence of velocities on luminosity (Fine et al. 2008, 2010 do not find such dependence). We got an average relationship $M_{BH} \propto L_{i,rest}^{0.605 \pm 0.005}$ (derived from c_1 in Table 1 for $z \leq 1.9$). Since roughly $L_{i,rest}$ is proportional to $L_{bol.}$[1] it is also logical that the result we get is $\epsilon \propto L_{I,rest}^{0.362 \pm 0.005}$ (derived from c_2 in Table 1 for $z \leq 1.9$); that is, the most massive black holes do not accrete at their Eddington luminosity, but rather all fall well shorter (Steinhardt & Elvis 2010).

The most interesting result here is that both M_{BH} and ϵ do not significantly depend on the redshift for a fixed luminosity, and there is not circularity in this result. This is very well illustrated in Fig. 1, where the change in color (representative of masses) is produced in the horizontal direction (change of luminosities) but not in the vertical direction (change of redshifts). There is not circularity because there are no reasons to think a priori that the rotation speeds given by the widths of the broad lines are dependent on or independent of the redshift, and the width of the broad lines is the only variable in which such a dependence could arise (see, for instance, Eq. (3.1])). From the values of b_1, b_2 for $z \leq 1.9$, we get that

$$\left\langle \frac{\partial M_{BH}}{\partial z} \right\rangle = (0.138 \pm 0.012) M_{BH}, \tag{4}$$

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[1] We must bear in mind that $L_{bol.}$ in S08 is given by a linear relationship with the continuum luminosity at a given wavelength, and since the average rest-colors of QSOs do not change significantly with redshift, the proportionality of different luminosities is expected.

$$\left\langle \frac{\partial \epsilon}{\partial z} \right\rangle = (-0.154 \pm 0.012)\epsilon. \tag{5}$$

The errors only stand for the statistical errors, not for the systematic errors which, as shown in Section 3, might be of the order of the given signal. This means that the variation of mass for QSOs of the same luminosity is around 14% per unit redshift, and the variation of the Eddington ratio is around -15% per unit redshift. This is quite small taking into account that the masses of the observed $z \approx 2$ SDSS QSOs are on average 10 times more massive and have four times higher Eddington ratios than at $z = 0.2$ (McLure & Dunlop 2004). So the conclusion is clear: the variation of mass and Eddington ratio at high redshift with respect to low redshift is due mainly to selection effects in luminosity. If we could observe QSOs at high-z as faint as low-z QSOs, then they would have roughly the same mass and the same Eddington ratio than the low-z ones.

Steinhardt & Elvis (2010) also considered this non-evolution: they found that the maximum luminosity of the QSOs is given by a sub-Eddington limit of $L = \alpha M * L_0$ and the slope $\alpha(z) = (0.41 \pm 0.09) + (0.12 \pm 0.08)z$, that is compatible with no evolution.

Croom (2011) also analyzed the black hole masses obtained by S08 data, although with a different method: using a Kolmogorov-Smirnov test to compare the distributions of M_{BH} for different redshifts and luminosities with those with randomized emission line velocities. Croom (2011) concludes that broad-line widths do not have a significant impact on the estimation of black hole mass. This is the same thing as saying that the mass of the black hole only depends on its luminosity, which is in agreement with our results. Implicitly, Croom (2011) or previously S08 already gave some information which could lead to our results. However, these authors were not explicit about the consequences in terms of a "non-evolution." Indeed, Croom (2011) did not mention anything about this non-evolution of the QSOs which we believe to be an important point to be discussed as a separate topic. The aim by Croom (2011) is that black hole masses only depend on their luminosities, whereas our aim remarks that black hole masses do not depend on redshift (for a constant luminosity). Apart from the different method of the double-linear fit, which can be taken as an independent confirmation of Croom (2011) result, we also extend our analysis to the systematic errors (see Section 3) and, rather than discussing the luminosity dependence, we are herein more interested in discussing the non-dependence on the redshift.

On average for $z \leq 5$ (the first row in Table 1; neglecting the dependence on redshift, taking the value for the average redshift $z = 1.35$): $\epsilon \approx 0.069 \times 0.738^{(M_i+23)}$ (M_i in AB magnitude). Taking into account that $L_{bol} = 6.8 \times 10^{36} \times 10^{-0.376M_B}$ erg/s (McLure & Dunlop 2004) (M_B in Vega magnitude), and an average color $\langle i(AB) - B(Vega) \rangle \approx 0.2$ (this comes from an average spectrum of a quasar in optical being $F_\nu \propto \nu^{-0.5}$ [Richards et al. 2001], and the difference $B(Vega) = B(AB) + 0.16$), we get

$$\epsilon \approx 0.22 \left(\frac{L_{bol}}{10^{47} \ erg/s} \right)^{0.35} \tag{6}$$

$$\left(\frac{M_{BH}}{10^9 \ M_\odot} \right) \approx 3.4 \left(\frac{L_{bol}}{10^{47} \ erg/s} \right)^{0.65}, \tag{7}$$

3 COMPLEMENTARY ANALYSES

Here we present a similar analysis by using our own estimations of masses and luminosities. We also discuss the reliability and uncertainties of the different methods used to estimate the black hole masses and luminosities and how they affect the results presented in the previous section. We used the sample of QSOs in SDSS-DR7 (Abazajian et al. 2009) fitting the continuum and the approppriate emission lines following the method outlined in Gutiérrez & López-Corredoira (2010). We used H_α (only for $z < 0.333$), H_β and [OIII]-5007Å, and the continuum for QSOs with $z < 0.787$, $M_B < -23$, and $FWHM > 2000$ km/s. We used the absolute magnitude in B derived from the interpolation of the different filters, rather than the i-band absolute magnitude with K-corrections. Only cases in which the
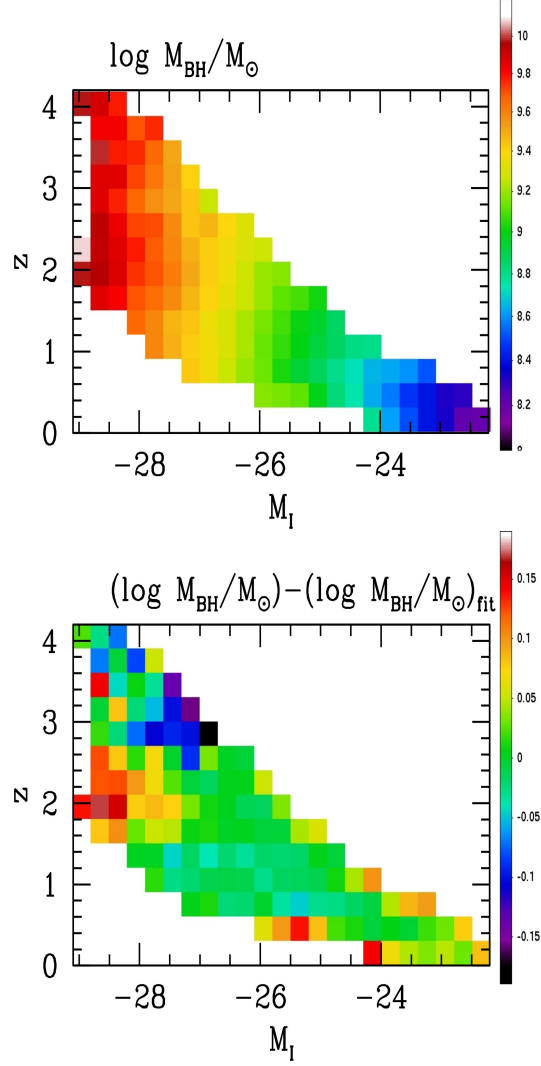
Fig. 1 (Top) Average of $\log_{10} M_{BH}$ (logarithm of the black hole mass) in bins of $\Delta z = 0.3$ in redshift and $\Delta M_i = 0.3$ in the i-rest absolute magnitude. ($Bottom$) Difference between the data and the best fit model.

heights of [OIII]-5007Å and H$_\beta$-broad lines were more than 3σ over the continuum, and those of H$_\alpha$-broad lines were more than 5σ over the continuum were chosen. The number of QSOs selected was 4954. Our sample is smaller than the one by S08 at $z < 0.7$ because we took a brighter constraint in brightness ($M_B < -23$ instead of $M_i < -22$).
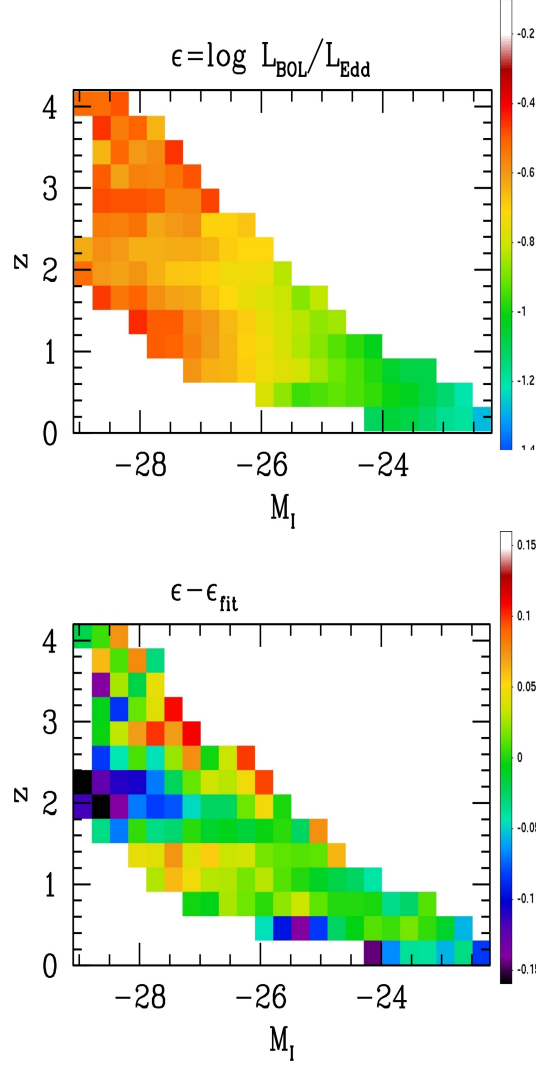
Fig. 2 *Top* Average of $\log_{10} \epsilon$ (logarithm of the Eddington ratio) in bins of $\Delta z = 0.3$ in redshift and $\Delta M_i = 0.3$ in the i-rest absolute magnitude. (*Bottom*) Difference between the data and the best fit model.

3.1 Estimators of black hole masses

There are several ways to calculate black hole masses (McGill et al. 2008), which basically differ in the lines used and the way to estimate the size of the broad line regions: either the luminosity of a line or the luminosity of the continuum. For the broad-line region velocity there is a general consensus that it is obtained from the square of the width of some broad line. The different methods can differ by up to 0.38 ± 0.05 dex in the mean, or 0.13 ± 0.05 dex, if the same virial coefficient is adopted (McGill et al. 2008). This error mainly affects the calibration of the coefficients a_1, a_2 given in Table 1, but also

Table 1 Bilinear fit of $\log_{10} M_{BH} = a_1 + b_1 z + c_1(M_i + 23)$ and $\log_{10} \epsilon = a_2 + b_2 z + c_2(M_i + 23)$ of the S08 sample. The first column indicates the redshift range used, and in brackets the corresponding line used for the determination of masses and bolometric luminosity. N is the number of QSOs. The quoted uncertainties are the statistical 1σ errors.

Range of z	N	a_1	b_1	c_1	a_2	b_2	c_2
All ($z \leq 5.0$)	49213	8.208 ± 0.003	$+0.052 \pm 0.004$	-0.250 ± 0.002	-1.103 ± 0.003	-0.042 ± 0.004	-0.132 ± 0.002
$z \leq 0.7$	8417	8.289 ± 0.017	-0.097 ± 0.044	-0.266 ± 0.008	-1.184 ± 0.017	$+0.147 \pm 0.043$	-0.100 ± 0.008
$0.7 < z \leq 1.9$	32738	8.153 ± 0.006	$+0.082 \pm 0.006$	-0.251 ± 0.002	-1.069 ± 0.006	-0.093 ± 0.006	-0.146 ± 0.002
$1.9 < z \leq 5.0$	8058	8.176 ± 0.023	-0.067 ± 0.009	-0.326 ± 0.007	-1.050 ± 0.023	$+0.095 \pm 0.009$	-0.042 ± 0.007
$z \leq 1.9$	41155	8.216 ± 0.004	$+0.060 \pm 0.006$	-0.242 ± 0.002	-1.105 ± 0.004	-0.067 ± 0.006	-0.145 ± 0.002

Table 2 Bilinear fit of $\log_{10} M_{BH} = a_1 + b_1 z + c_1(M_B + 23)$ and $\log_{10} \epsilon = a_2 + b_2 z + c_2(M_B + 23)$ of our sample (see Section3), and the estimators of mass and bolometric luminosity given in Section3. The first column indicates the redshift range and the line/cont. used for the determination of the bolometric luminosity; c.e. indicates correction of total extinction for the flux of H_β. N is the number of QSOs. The given errors are only statistical values.

Lines	N	a_1	b_1	c_1	a_2	b_2	c_2
$z < 0.787$/OIII	4954	8.43 ± 0.02	-0.23 ± 0.04	-0.293 ± 0.008	-0.80 ± 0.03	0.20 ± 0.04	-0.055 ± 0.010
$z < 0.787$/M_B	"	" "	" "	" "	-1.06 ± 0.02	0.23 ± 0.04	-0.083 ± 0.008
$z < 0.787$/Cont.5100	"	" "	" "	" "	-1.10 ± 0.02	0.06 ± 0.04	-0.095 ± 0.007
$z < 0.333$/OIII	218	8.30 ± 0.10	-0.13 ± 0.35	-0.31 ± 0.04	-0.58 ± 0.15	-0.07 ± 0.55	-0.03 ± 0.06
$z < 0.333$;c.e./OIII	"	8.25 ± 0.12	0.01 ± 0.45	-0.29 ± 0.05	-0.53 ± 0.15	-0.22 ± 0.55	-0.04 ± 0.06

the coefficients b_1, b_2. In order to illustrate this fact, we have carried out calculations of masses with an estimator different from S08, using the flux of H_β instead of the flux of the continuum to derive the size of the broad line region (Green & Ho 2005)

$$M_{BH}(H_\beta) = 1.5 \times 10^8 \left(\frac{L_{H_\beta}}{3.8 \times 10^{43} \text{ erg/s}} \right)^{0.56} \tag{8}$$

$$\left(\frac{\sigma_{H_\beta}}{1000 \text{ km/s}} \right)^{2.00} \text{M}_\odot.$$

The result, as given in Table 2, is an a_1 around 0.15 dex larger than that with the S08 sample at $z < 0.7$, and b_1 around 0.15 dex smaller, so we must conclude that the systematic errors associated with the mass estimators are of this order in a_1 and b_1, 0.1-0.2 dex, much larger than the statistical errors. Note that, using this method, since we truncate the sample of QSOs with low height of the H_β line (which means very high velocity), for a given luminosity of the line, we might remove some very high mass candidates, and introduce some bias. However, the aim here was checking the robustness of the mass estimator, and the "unbiased" statistics are only carried out with the method in Section 2.

3.2 Estimators of bolometric luminosities

Here we will compare three different methods, and the differences between them will give us an estimation of the systematic errors associated with that calculation.

– Using the luminosity of the [OIII]-5007Å line ($L_{OIII,5007}$; corrected for Galactic extinction) (Heckman et al. 2004):

$$L_{bol_1} = 3500 \, L_{OIII,5007} \tag{9}$$

We assume for QSOs that the luminosity of OIII lines due to star formation is negligible. There is however another more important correction to carry out. Due to the small diameter of the SDSS fiber (3"), we may lose some small amount of light if the OIII region is somewhat spread. According to Bennert et al. (2002), the linear radius of the OIII regions is:

$$R_{OIII} \approx 3.2 \times 10^{-19} \left(\frac{L_{\mathrm{OIII,5007}}}{ergs^{-1}} \right)^{0.52} \ \mathrm{pc}, \tag{10}$$

and with a surface brightness having radial dependence $L(r) \propto r^{\delta}$ (Bennert et al. 2006) and an average $\delta = -2.95$, we get that at half of R_{OIII}, it is equivalent to a Gaussian distribution with $\sigma \sim 0.3 R_{OIII}$. This σ must be quadratically added to the seeing for OIII lines, while the continuum covers a much reduced area and its spread only stems from the seeing. For a Gaussian distribution of light, the amount of lost light outside a fiber of radius θ_f (=1.5" for SDSS) will be $Lost_{\sigma} = e^{-\frac{1}{2}\left(\frac{\theta_f}{\theta_\sigma}\right)^2}$ where θ_σ is the angular size corresponding to the linear size of σ (using the standard cosmological parameters). The corrected luminosity will be $L_{OIII,5007}^{corr.} = \frac{L_{OIII,5007}}{1 - Lost_{\sigma - OIII} + Lost_{\sigma - cont.}}$. This correction is small ($< 5\%$) in most of the cases but more significant in some sources, in particular at low z.

There might also be some dependence on this relationship with the type of AGN (Netzer 2010). We assume that the difference from the Seyfert 1 used by Heckman et al. (2004) and QSOs is negligible. A more precise estimator would be obtained using both [OIII] and [OI] lines (Netzer 2010), but [OI] would be more affected by star formation contamination and lost of light outside the fiber due to its higher spread.

– Using the absolute magnitude in the B-band with K-correction and correction for Galactic extinction, M_B (Vega calibrated) (McLure & Dunlop 2004, eq. (C1))

$$L_{bol_2} = 6.8 \times 10^{36} 10^{-0.376 M_B} \ \mathrm{erg/s} \tag{11}$$

– Using the continuum luminosity at 5100 Å (McLure & Dunlop 2004, SectionC1)

$$L_{bol_3} = 9.8 [\lambda L_{cont.\lambda}] (5100 \ \mathring{A}), \tag{12}$$

where $L_{cont.\lambda}$ is the luminosity per unit wavelength at a given λ at rest, and includes Galactic extinction correction as well. This is the method used by S08, although with their own calibration.

With the three different methods, we get values of b_2 equal to 0.20, 0.23 and 0.06 respectively, to be compared with 0.15 for the S08 subsample at $z < 0.7$. Again we see that the uncertainties due to the use of different estimators are on the order of 0.1-0.2 dex in the coefficient b_2.

3.3 Extinction

Apart from the Galactic extinction, which is easy to correct, there might be some intergalactic extinction, extinction from the host galaxy of the QSO, and extinction from the torus of the QSO itself. These would affect the measured fluxes, either for the lines or the continuum. We will explore herein the relevance and consequence of this effect.

The ratio of the broad lines H_α, H_β can be used to derive the extinction in each galaxy; the luminosities corrected for extinction (using Dessauges-Zavadsky et al. 2000, which assumed a ratio of 3.1 for AGNs, and that the variations of this value are due only to extinction) would be

$$L_{H_\alpha}^{c.e.} = \frac{L_{H_\alpha}^3}{3.1^2 L_{H_\beta}^2}, \qquad L_{H_\beta}^{c.e.} = \frac{L_{H_\alpha}^{c.e.}}{3.1}, \tag{13}$$

Due to the spectral coverage of SDSS spectra, H_α is only available within $z < 0.333$, which means there are 218 QSOs in our sample. La Mura et al. (2007) also used Balmer lines AGNs with z ¡ 0.4 in their

analysis. In this subsample, we can carry out the calculation of the masses with the extinction corrected fluxes. The results are presented in Table 2. Here, due to the low number of QSOs, the statistical errors are larger than the effect of the extinction correction. Anyway, apart from the statistical errors (which are equal with or without extinction correction), we can see that the extinction effect reduces by 0.1-0.2 dex the value of the b_1 and increases b_2 by the same amount.

A bilinear fit of the ratio of both Balmer lines gives

$$\log_{10} \frac{F_{H_\alpha}}{3.1 F_{H_\beta}} = (-0.035 \pm 0.051) + (0.11 \pm 0.19)z \tag{14}$$

$$+(0.005 \pm 0.022)(M_B + 23),$$

so no significant dependence on redshift is found and then no significant detection of intergalactic extinction (which should be increasing with z) was found.

4 CONCLUSIONS AND DISCUSSION

The main conclusion of our analysis is that both the mass and the Eddington ratio of the black holes for a QSO with a given luminosity do not evolve with redshift. Or in other words, the luminosity of a QSO does not evolve with redshift for a given mass. More precisely and considering systematic uncertainties $\sim 0.2 - 0.3$ dex in the estimation of masses and luminosities, we conclude that the evolution in redshift, if any, is very small compared to the change in mean luminosity of the population of QSOs at low redshift with respect to such a population at high redshifts. This implies an important result on the nature of QSOs, i.e. local QSOs are intrinsically less massive than QSOs at high redshift. Labita et al. (2009a) derived that the maximum mass of a black hole in a QSO is a function of the redshift: $\log_{10} M_{BH} = (0.34z + 8.99)$ M$_\odot$ up to redshift 1.9, or proportional to $(1 + z)^{1.64}$ if extended up to a redshift of 4 (Labita et al. 2009b). This lack of the signature of active massive AGN black holes in the local Universe cannot be related with a possible decline in the rate of formation of QSOs (this would affect the density of QSOs but not their average mass; and indeed there is evidence for the change in the comoving density of QSOs of a given mass; Steinhardt & Elvis 2011, fig. 3), but because of some mechanism for the formation of huge black holes which took place in the past in the Universe, which is absent in the present Universe.

NOTE: Do not confuse the non-evolution of the black hole mass-luminosity ratio (the result of this paper) with the non-evolution of mechanisms which produce such black holes. Evidently, as said in the introduction, some evolution in the birth of new QSOs must take place in order to explain the absence of very bright QSOs at low redshift.

The fact that the Eddington ratio of the QSO does not change with z for a given luminosity/mass counters scenarios which explain the evolution of the luminosity of QSOs in terms of the change in the environment of the AGNs, like variations in the accretion rate. Our result is at odds with the common assumption that relates the influence of companion galaxies with the mechanism of feeding the black hole of the QSO (Stockton 1982; Canalizo & Stockton 2001). Horst & Duschl (2008) presented the results of a simple cosmological model combined with an evolutionary scenario in which both the formation of the black hole as well as the gas accretion onto it are triggered by major mergers of gas-rich galaxies. Despite the very generous number of approximations, their model reproduces the quasar density evolution in remarkable agreement with some observations. However, we do not see this decrease of gas accretion here, so the environment does not seem to be the major factor responsible for the change in luminosity of QSOs. We do not deny, however, the effect of the environment on the mechanism of formation/turn-off of its own massive black hole, although the synchronization of all very-massive QSOs in an epoch turning off nearly at the same time is not understood, because galaxies continue to merge and virialize at some rate at later epochs (Steinhardt & Elvis 2011).

Other results from other papers are also apparently at odds with the idea of powerful AGNs in a rich highly interactive environment. Coldwell & Lambas (2006) showed that quasars at $z < 0.2$ systematically avoid high density regions, living in regions less dense than cluster environments. At

$0.5 \leq z \leq 0.8$, only 10% of QSOs live in relatively rich clusters, and 45% of them in field-like environments (Wold et al. 2001). We might also consider that galaxies in rich clusters are stripped of their interstellar medium by harassment, so it would be reasonable that the QSO activity is less than in the field galaxies, but the ratio of spiral galaxies with non-stripped gas is still high enough to consider that there should be activity being triggered. More recently, Cisternas et al. (2011) showed directly that there is not an enhanced frequency of merger signatures for the AGN hosts with respect to other galaxies, so this points out that mergers should not be an important element for the triggering of activity.

There are other kind of models on the origins and the early evolution of QSOs and supermassive black holes (review at Djorgovski et al. 2008). Many works have related the evolution of QSOs with their star formation ratios; e. g. Haiman et al. (2007) assume that star formation in spheroids (elliptical galaxies and bulges of late-type galaxies) and black hole fueling are proportional to one another at all times, and fitting conveniently some parameters get a model of luminosity evolution of QSOs in agreement with observed data with quasar lifetimes $\approx 6 - 8 \times 10^7$ yr, without a compelling need for any of the model parameters to evolve with redshift between $0 < z < 6$. This result supports the direct connection between the build up of spheroids and their nuclear supermassive-black-holes.

The existence of very massive black holes is only at high z. Perhaps it could be related with the higher ratio of mergers and then star formation in the past. We wonder whether it might have something to do with the excess of very massive galaxies at high-z, which is still not completely understood within semianalytical hierarchical ΛCDM models (e.g., Fontana et al. 2009). Indeed, the mass of the black hole has remained proportional to the stellar mass of their host galaxies for at least the last 9 Gyr (Jahnke et al. 2009). Or perhaps it has something to do with the larger average density of the Universe, or the angular momentum of some components of the galaxies (at high z, the black holes rotate faster; Netzer 2010). However, where are the black holes with masses larger than 10^{10} M$_\odot$ which were frequent in the past? We do not know any mechanism by which black holes can reduce its mass. Also, one should not lose sight of some solutions in which, for some reason (e.g., radiation emitted in beams rather than isotropically over 4π stereoradians, non-cosmological redshifts, wrong cosmological model, etc.), the luminosity of the QSOs does not correspond to $4\pi d_L(z)^2 Flux$, with $d_L(z)$ the luminosity distance given by standard cosmology, and consequently both the luminosities and the masses[2] would be erroneously determined. Clearly the question remains open and it is beyond the scope of the present paper.

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[2] The calculation of the mass depends on the luminosity of the continuum, like in the application by S08, or of some line, like in Eq. (3.1). Note, moreover, that there is not a significant variation of the width of broad lines with redshift (S08, fig. 3) so this reinforces the idea that huge masses are obtained because huge luminosities are measured, and an overestimation of the luminosity directly produces an overestimation of the masses.

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